PROGRAM DESCRIPTION

Description of Operation

Vehicle/Powertrain Configuration

The electric vehicle model is based upon conventional component arrangements as shown in Figure 31. The battery is electrically connected to the inverter/controller. Auxiliary loads and auxiliary power units are also assumed to be directly connected to the traction battery. The motor and inverter/controller are also connected via a direct electrical connection. The single motor is mechanically connected to the vehicle wheels through a transmission which may have either 1 or 2 gear ratios. Losses between components are not explicitly modeled (e.g. electrical transmission losses) but may be included in the component efficiency definitions if desired. Friction and windage losses in rotating components are associated with the particular component and also may be reflected in the efficiency maps.

Road Load Power

In theory, SIMPLEV's operation is easily understood; the power required at the driveshaft of the vehicle to move the vehicle from the speed at one time step to the speed at the next time step (i.e., v_{t-1} to v_t) is calculated using:

$$P(t) = P_{acc} + P_{grade} + P_{aero} + P_{rolling} + P_{bearing}$$

$$P_{acc} = (M_e \cdot dv(t)/dt) \cdot v(t)$$

$$P_{grade} = W \cdot \sin(\Theta) \cdot v(t)$$

$$P_{aero} = [½\, \rho\, C_d(\gamma) \cdot A v_r(t)^2] \cdot v(t)$$

$$P_{rolling} = [(C_0 + C_1 v(t) + C_2 v(t)^2 + C_3 v(t)^3) \cdot W] \cdot v(t)$$

$$P_{bearing} = \tau_B \cdot s_w(t)$$

Figure 31

where:

$P(t)$ = power as a function of time

P_{acc} = acceleration/deceleration inertia power

P_{grade} = power associated with gravity

P_{aero} = aerodynamic drag power

$P_{rolling}$ = rolling resistance power

$P_{bearing}$ = wheel bearing loss power

M_e = mass equivalent, includes rotational inertia of 3% of vehicle weight (i.e., $M_e = 1.03 \cdot W/g$,

g = acceleration of gravity

ρ = density of air

$C_d(\gamma)$ = aerodynamic drag coefficient as a function of wind yaw angle γ

A = frontal area of vehicle

$v(t)$ = vehicle speed as a function of time

$v_r(t)$ = relative wind speed in direction of travel as a function of time

C_0, C_1, C_2, C_3 = coefficients of rolling resistance

W = weight of vehicle

τ_B = wheel bearing torque drag

Θ = road grade angle measured from horizontal

$s_w(t)$ = wheel speed as a function of time.

The aerodynamic drag coefficient input by the user, C_d, is corrected for wind yaw angle according to the following equations:

$$v_{wind,x}(t) = -v(t) \cdot \sin(\alpha) - v_{wind} \cdot \sin(\beta)$$

$$v_{wind,y}(t) = -v(t) \cdot \cos(\alpha) - v_{wind} \cdot \cos(\beta)$$

$$v_r(t) = [(v_{wind,x}(t))^2 + (v_{wind,y}(t))^2]^{1/2}$$

$\psi \qquad = \tan^{-1}(v_{wind,x} \div v_{wind,y})$

$\gamma \qquad = \alpha - \psi$

$C_d(\gamma) \qquad = C_d(1+a\cdot|\gamma|^b)$, for $|\gamma| \leq 17.5^\circ$

and

$|\gamma| \qquad = 17.5^\circ$ for $\gamma > 17.5^\circ$

where:

$v_{wind,x}(t)$ = component of air speed relative to vehicle in direction of travel

$v_{wind,y}(t)$ = component of air speed relative to vehicle perpendicular to direction of travel

α = vehicle direction of travel (North=0)

β = wind direction (North=0)

v_{wind} = wind speed in direction β

ψ = wind direction relative to vehicle

$v_r(t)$ = wind speed relative to vehicle

γ = wind yaw angle (direction of $v_r(t)$ relative to vehicle)

a and b = coefficients input by the user. Default values of a = 0.00194 and b = 1.657026 are assumed in lieu of values specified by the user.

Driveshaft/Transmission Power

The driveshaft torque is dependent upon the resultant direction (positive or negative) of the road load power, P_d. If the power required is positive, the power at the driveshaft of the vehicle is calculated as:

$$P_d(t) = P_{acc} + P_{grade} + P_{aero} + P_{rolling} + P_{bearing}$$

If the power required to move the vehicle from v_{t-1} to v_t is negative, the power at the driveshaft is calculated as:

$$P_d(t) = P_{acc} + P_{grade}$$

This latter case represents power which must be absorbed to slow the vehicle (i.e., when $v_{t-1} - v_t < 0$) when $P_d < 0$.

The driveshaft torque, τ_d, is then calculated from the vehicle speed, v_t, and the tire rolling radius, r, for the appropriate condition. These relationships are as follows:

$$s_w = v_t \div 2\pi r$$
$$\tau_d = P_d \div s_w,\ \ P_d > 0$$
$$\tau_d = f_r \cdot (P_d \div s_w),\ \ P_d < 0$$

where:

f_r is the fraction of torque available for regenerative braking. Conversely, $1\text{-}f_r$ is the fraction of torque absorbed in the vehicle friction brakes.

Tire Slip Limits. The maximum possible wheel force for both acceleration, $F_{w,max,a}$, and deceleration, $F_{w,max,d}$, is calculated from the following formulas:

$$F_{w,max,a} = \mu_o \cdot W \cdot f_d$$
$$F_{w,max,d} = \mu_o \cdot W$$

where:

μ_o = coefficient of static friction between the vehicle tires and the road

f_d = fraction of vehicle weight supported by the drive wheels

If either of these limits are exceeded while attempting to attain the desire target speed, SIMPLEV iterates a solution for vehicle speed whereby these limits are not exceeded. Under these conditions, the maximum road/wheel traction under acceleration and deceleration is afforded.

Motor

Using the driveshaft torque and speed, the efficiency is then determined from the data input via the transmission file for the appropriate gear ratio using a double linear interpolation scheme. From the calculated driveshaft power, P_d, and the transmission efficiency, η_{tr}, the power at the transmission/motor interface, P_m, is calculated from

$$P_m \quad = P_d \cdot \eta_{tr}, \text{ for } P_d < 0 \text{ (regenerative braking quadrant of operation)}$$

$$P_m \quad = P_d \div \eta_t \text{ for } P_d > 0 \text{ (driving quadrant of operation).}$$

The motor speed, s_m, and motor torque, τ_m, is then calculated from the transmission gear ratio, r_{gear}, the transmission driveshaft speed, and previously calculated motor power P_m:

$$s_m \quad = s_d \cdot r_{gear}$$
$$\tau_m \quad = P_m \div s_m.$$

From the motor torque and speed, the motor efficiency, η_m, is obtained via a double linear interpolation. Since the inverter/controller efficiency tables are also given in terms of motor output speed and torque, the inverter/controller efficiency is likewise determined.

Maximum Motor Torque. At this point, a check is performed to determine if the maximum motor torque envelope has not been exceeded; comparing τ_m to the interpolated maximum torque value, $\tau_{m,max}$, from the motor file. If the maximum motor torque envelope has been exceeded, τ_m is set equal to $\tau_{m,max}$ and a solution for the following relationship is found by iteration of v_t:

$$P_{m,max} \quad = P_d \div \eta_{tr}$$

where $P_{m,max}$ is a function of motor speed, P_d is a function of vehicle speed, and η_{tr} is a function of driveshaft torque and speed.

Under acceleration, this solution gives the fastest speed possible within the maximum motor torque envelope. Under deceleration, the maximum amount of regeneration power is returned to the battery.

Inverter/Controller

From the motor power, P_m, and the motor efficiency at the current operating point, η_m, the power at the motor/(inverter/controller) interface, P_i, is calculated by one of the following relationships:

$P_i = P_m \cdot \eta_m$, for $P_m < 0$ (regenerative braking quadrant of operation)

$P_i = P_m \div \eta_m$ for $P_m > 0$ (driving quadrant of operation).

Battery

From the inverter/controller power, P_i, and the inverter/controller efficiency at the current operating point, η_i, the traction power at the battery/(inverter/controller) interface, $P_{B,tract}$, is calculated by one of the following relationships:

$P_{B,tract} = P_i \cdot \eta_i$, for $P_i < 0$ (regenerative braking quadrant of operation)
$P_{B,tract} = P_i \div \eta_i$, for $P_i > 0$ (driving quadrant of operation).

The total battery power, $P_{B,total}$, is determined by algebraically adding any power contributed by the auxiliary power unit, $P_{B,APU}$, and auxiliary loads $P_{B,aux}$ as follows:

$P_{B,total} = P_{B,APU} + P_{B,aux} + P_{B,tract}$.

By convention, battery power and current is positive out of the battery (discharge) and negative into the battery (discharge). By this rule, $P_{B,aux}$ is generally positive and $P_{B,APU}$ is generally negative.

From the calculated total battery power, $P_{B,total}$, and the battery characteristics (i.e., open circuit voltage, V_{OC}, and resistance, dV/dI_B at the current depth-of-discharge) is found by linear interpolation of the data input via the battery file, the battery current (I_B) is determined by solving for the real root of the quadratic equation:

$P_{B,total} = dV/dI \cdot I_B^2 + V_{OC} \cdot I_B$

which is given by:

$$(-V_{OC}+(V_{OC}^2-4 \cdot dV/dI \cdot P_{B,total})^{1/2}) \div 2 \cdot dV/dI.$$

The battery voltage under load, V_B, is then calculated from the relationship:

$$V_B = P_{B,total} \div I_B$$

Since the battery, auxiliary power unit, auxiliary loads, and powertrain are assumed to be electrically connected in parallel (Figure 31), the respective current to each of these components can be calculated as follows:

$$I_{APU} = P_{APU} \div V_B$$
$$I_{aux} = P_{aux} \div V_B$$
$$I_{tract} = P_{B,tract} \div V_B \, .$$

Minimum Voltage

The calculated battery voltage, V_B, is then compared to the minimum voltage, V_{min}, as specified by the user.

If $V_B < V_{min}$, then V_B is set equal to V_{min} and the maximum battery current at this voltage is found from the relationship:

$$I_{Vmin} = (V_{min} - V_{OC}) \div dV/dI$$

The remaining current and power at the minimum battery voltage available to the powertrain is then calculated:

$$I_{Vmin,tract} = I_{Vmin} - (P_{APU} \div V_B) - (P_{aux} \div V_B)$$

$$P_{tract,Vmin} = I_{Vmin,tract} \cdot V_{min}$$

A solution for v_t is then found by iteration which satisfies the relationship:

$$P_{tract,Vmin} = P_d \div (\eta_{trans} \cdot \eta_m \cdot \eta_i)$$

where:

P_d is a function of vehicle speed; and η_{trans}, η_m, and η_i are ultimately functions of the driveshaft torque and vehicle speed, (τ_d and v_t).

This solution gives the maximum vehicle speed possible while being constrained by the minimum battery voltage.

Maximum Current

The calculated current required to the powertrain is compared to the maximum allowable current, I_{max}, which is a function of motor speed, s_m. If the maximum current for the calculated motor speed is encountered (i.e., $I_{tract} > I_{max}$) then I_{tract} is set equal to $I_{max,tract}$, and the battery voltage, V_B, is determined from the relationship:

$$V_B = V_{OC} - (I_{max}+I_{APU}+I_{aux}) \cdot dV/dI.$$

This battery voltage, V_B, is then compared to the minimum voltage, V_{min}, specified by the user. If $V_B < V_{min}$, then V_B is set equal to V_{min} and the procedure outlined above is followed. If $V_B \geq V_{min}$, the maximum power available to the powertrain, P_{tract}, and the currents required for auxiliary loads, auxiliary power unit, and total battery current, I_B, is calculated according to the following relationships:

$$P_{tract} = V_{min} \cdot I_{max}$$
$$I_{aux} = P_{aux} \div V_{min}$$
$$I_{APU} = P_{APU} \div V_{min}$$
$$I_B = I_{max}+I_{aux}+I_{APU}.$$

A solution for v_t is then found by iteration, that satisfies the relationship:

$P_{tract},V_{min} = P_d \div (\eta \cdot \eta_m \cdot \eta_i)$.

where:

P_d is a function of vehicle speed; and η, η_m, and η_i are ultimately functions of the driveshaft torque and vehicle speed, (τ_d and v_t).

Auxiliary Power Unit

In a series hybrid, the key considerations in specifying the control strategy (i.e., battery DOD at which the vehicle switches into and out of hybrid operation and generator output power) are modeled in SIMPLEV. The constant generator output mode is straightforward and need not be described here. However, the variable power mode requires some explanation.

Variable Generator Output. The generator power, P_{gen} is based upon minimum and maximum values selected by the user and the average power required to propel the vehicle on the driving cycle during the previous time period. The average power, P_{av}, is calculated by averaging the traction power (power input to the inverter/controller) over a specified time period, Δt_{gen} as follows:

$$P_{av} = \Sigma P_{tract} \div \Delta t_{gen}$$

P_{gen} is then calculated by:

$$P_{gen} = fg \cdot P_{av}$$

fg is a user input factor, and P_{gen} is subject to the maximum and minimum specified power allowed, such that:

if $P_{gen} < P_{gen,min}$, then $P_{gen} = P_{gen,min}$
if $P_{gen} > P_{gen,max}$, then $P_{gen} = P_{gen,max}$.

The efficiency, η_{gen} , of the generator is input as a function of P/P_{max} based on available test data.

The output power of the engine is given by:

$$P_{eng} = P_{gen} / \eta_{gen}$$

where P_{gen} is the power out of the engine, and η_{gen} is the generator efficiency.

The fuel used (Δfu) at each time increment Δt; is calculated from:

$$\Delta fu = bsfc \cdot P_{eng} \cdot \Delta t_i /3600$$

$$\Delta fu = bsfc \cdot P_{eng} \cdot \Delta t_i /3600 \cdot (/(\rho_f)$$

where bsfc is the brake specific fuel consumption (gm/kW·h) of the engine and ρ_f is the density of the fuel. The emissions of HC, CO, NO_X out of the engine in time increment Δt_i are given by:

$$\Delta(HC,CO,NO_X)_{eng} = (gm/kW{\cdot}h)\ HC,CO,NO_X \cdot P_{eng} \cdot t_i$$

where:

(gm/kW·h) HC, CO, NO_X are the specific emissions of the engine.

The emissions downstream of the catalytic converter are:

$$e(HC,CO,NO_X)_{cat} = e(HC,CO,NO_X)_{eng} \cdot [1 - \eta_F(HC,CO,NO_X)_{cat}]$$

where:

η_F (HC, CO, NO_X) are the conversion efficiencies of the catalyst for the pollutants HC, CO, and NO_X. The efficiency of the catalyst depends on its temperature and thus it increases with time when the engine is turned on and decreases with time after the engine is turned off. These effects are modeled by expressing the catalyst efficiency as:

$$\eta_e/\eta_o\ (HC,CO,NO_X) = 1- e^{-\ (te/tc)}$$

where t_e is the effective time the engine is on, t_c is the characteristic time for warm-up of the catalyst, and η_o (HC, CO, NO_X) are the steady state conversion efficiencies of the catalyst for HC, CO, and NO_X. The effective on-time of the engine is calculated as follows:

engine on $\quad t_e = t_e + \Delta t_{on}$

engine off $\quad t_e = t_e - a \cdot \Delta t_{off}$

where "a" is a factor to account for the difference between the heat up and cool down times of the catalyst ("a" is usually taken to be less than 1.0). The maximum value of t_e permitted is that corresponding to η_e equal to 99% of η_o for each of the pollutants.

Battery Capacity and DOD

During the program execution, the ampere-hours into and out of the battery are summed as well as the average ampere-hours through the battery. These quantities are then divided by the appropriate time to calculate the average charge, discharge, and net current, respectively. This is shown by the following equations

$$I_{avg,charge} = \Sigma\,(I_{charge} \cdot \Delta t_{charge}) \div \Sigma \Delta t_{charge}$$

$$I_{avg,disch} = \Sigma\,(I_{disch} \cdot \Delta t_{disch}) \div \Sigma \Delta t_{dischg}$$

$$I_{avg} = \Sigma\,(I_B \cdot \Delta t) \div \Sigma \Delta$$

where:

$$Ah_{net}\Delta t = \Sigma\,(I_B \cdot \Delta t) \text{ in the above equation.}$$

The average battery current, I_{avg}, is used to calculate the available battery capacity from the Puekert relationship using the constants from the battery file. This equation is of the form:

$Ah_{Cap} = a \cdot I_{avg}{}^{b}$, where a and b are constants.

The depth-of-discharge (DOD) at each time increment of the simulation is then given by the following:

$DOD = Ah_{net} \div Ah_{Cap}$

Battery Scaling

Battery scaling methodology straightforward. After the user enters a modified battery ampere-hour capacity, the Puekert relationship, dV/dI versus DOD, and battery weight is adjusted according to the following relationships:

$Ah_{Cap,1} = Ah_{Cap}$

$(dV/dI_B)_1 = dV/dI_B \cdot Ah_{Cap,1} \div Ah_{Cap}$

$a_1 = b \cdot (Ah_{Cap,1} \div Ah_{Cap})^{1-b}$

$W_{module,1} = W_{module} \cdot Ah_{Cap,1} \div Ah_{Cap}$

where:

$Ah_{Cap,1}$ = the new ampere-hour capacity for which the battery is to be scaled

a_1 = new Peukert constant

$(dV/dI)_1$ represent the new values of battery dV/dI_B

$W_{module,1}$, W_{module} = new and initial battery module weight, respectively.

Energy

Energy calculations are based upon the summation of the calculated power at each component interface over the appropriate time intervals.

$E_{B,gross} = \Sigma (P_{B,total} \cdot \Delta t)$ when $P_{B,total} > 0$

$E_{B,chg} = \Sigma (P_{B,total} \cdot \Delta t)$ when $P_{B,total} < 0$

$E_{APU} = \Sigma (P_{APU} \cdot \Delta t)$ when $P_{APU} \neq 0$

$E_{aux} = \Sigma (P_{aux} \cdot \Delta t)$ when $P_{aux} \neq 0$

$E_{tract,driving} = \Sigma (P_{B,tract} \cdot \Delta t)$ when $P_{B,tract} > 0$

$E_{tract,regen} = \Sigma (P_{B,tract} \cdot \Delta t)$ when $P_{B,tract} < 0$

$E_{i,driving} = \Sigma (P_i \cdot \Delta t)$ when $P_i > 0$

$E_{i,regen} = \Sigma (P_i \cdot \Delta t)$ when $P_i < 0$

$E_{m,driving} = \Sigma (P_m \cdot \Delta t)$ when $P_m > 0$

$E_{m,regen} = \Sigma (P_m \cdot \Delta t)$ when $P_m < 0$

$E_{d,driving} = \Sigma (P_d \cdot \Delta t)$ when $P_d > 0$

$E_{d,regen} = \Sigma (P_d \cdot \Delta t)$ when $P_d < 0$

$E_{B,net} = E_{B,gross} - E_{B,chg}$

where:

$E_{B,gross}$ = total energy discharged from the battery

$E_{B,chg}$ = total energy into the battery

E_{APU} = total energy supplied by the auxiliary power unit

E_{aux} = total energy consumed by auxiliary loads

$E_{tract,driving}$ = total battery energy used for vehicle traction

$E_{tract,regen}$ = total battery energy recovered from regenerative braking

$E_{i,driving}$ = total energy out of inverter/controller

$E_{i,regen}$ = total energy into inverter/controller

$E_{m,driving}$ = total energy out of motor

$E_{m,regen}$ = total energy into motor

$E_{B,net}$ = net battery energy

$E_{d,driving}$ = total energy delivered to wheels

$E_{d,regen}$ = total energy at driveshaft from regenerative braking

Average Battery Power

The average battery discharge, charge, and net power is calculated from the appropriate energy divided by the appropriate total time via the following equations:

$$P_{avg,disch} = E_{B,gross} \div t_{disch}$$
$$P_{avg,chg} = E_{B,chg} \div t_{chg}$$
$$P_{avg} = E_{B,net} \div t$$

where:

$P_{avg,disch}$	= average battery discharge power
$P_{avg,chg}$	= average power into battery
P_{avg}	= average battery power
P_{disch}	= total time during battery discharge
t_{chg}	= total time during battery charge
t	= total time of simulation.

Average Component Efficiencies

The average component efficiencies are obtained for each mode of operation (driving and regeneration) by division of the appropriate calculated energy quantities. The specific average component efficiencies which are calculated in the simulation are given below:

$$\eta_{avg,trans,driving} = E_{d,driving} \div E_{m,driving}$$
$$\eta_{avg,trans,regen} = E_{m,regen} \div E_{d,regen}$$
$$\eta_{avg,m,driving} = E_{m,driving} \div E_{i,driving}$$
$$\eta_{avg,m,regen} = E_{i,regen} \div E_{m,regen}$$
$$\eta_{avg,i,driving} = E_{i,driving} \div E_{tract,driving}$$
$$\eta_{avg,i,regen} = E_{tract,regen} \div E_{i,regen}$$
$$\eta_{avg,ptrn,driving} = E_{d,driving} \div E_{tract,driving}$$
$$\eta_{avg,ptrn,regen} = E_{tract,regen} \div E_{d,regen}.$$

Battery Efficiency

The battery efficiency is obtained for each mode of operation (charge and discharge). The fictitious battery power assuming no dV/dI losses is calculated for each time step and summed to determine the total battery energy without losses. These energy values are then used to determine the battery energy efficiency according to the following equations:

$$P_{sys} = V_{OC} \cdot I_B$$
$$E_{sys,disch} = \Sigma\,(P_{sys} \cdot \Delta t) \text{ when } P_{sys} > 0$$
$$E_{sys,chg} = \Sigma\,(P_{sys} \cdot \Delta t) \text{ when } P_{sys} < 0$$
$$\eta_{avg,batt,disch} = E_{B,gross} \div E_{sys,disch}$$
$$\eta_{avg,batt,chg} = E_{B,chg} \div E_{sys,chg}.$$

Average Component Losses

The average component power losses are calculated from the energy through each component for each mode of operation as follows:

$$L_{B,disch} = (E_{sys,disch} - E_{B,gross}) \div \Sigma\Delta t$$
$$L_{B,chg} = (E_{B,chg} - E_{sys,chg}) \div \Sigma\Delta t$$
$$L_{m,driving} = (E_{m,driving} - E_{i,driving}) \div \Sigma\Delta t$$
$$L_{m,regen} = (E_{i,regen} - E_{m,regen}) \div \Sigma\Delta t$$
$$L_{i,driving} = (E_{i,driving} - E_{tract,driving}) \div \Sigma\Delta t$$
$$L_{i,regen} = (E_{tract,regen} - E_{i,regen}) \div \Sigma\Delta t$$
$$L_{trans,driving} = (E_{d,driving} - E_{m,driving}) \div \Sigma\Delta t$$
$$L_{trans,regen} = (E_{m,regen} - E_{d,regen}) \div \Sigma\Delta t$$

Coastdown Calculations

The calculation of vehicle coastdown times and loads is an iterative solution for the vehicle speed, v(t), in the road load equation wherein the energy dissipated via aerodynamic drag, wheel bearing drag, and tire losses are equal to the change in vehicle kinetic energy from one time step to the next. In other words, v(t) is found which satisfies the following equation:

$$-P_{acc} = P_{grade} + P_{aero} + P_{rolling} + P_{bearing}.$$

The coastdown times for the speed ranges listed in the simulation output are linearly interpolated from the calculated times at the speeds closest to the desired speeds.

Input Parameters and Component Definition

As previously described, the input parameters are either read from component files or input from the PC keyboard. The following sections describe the data contained in the component files and the format of these files. From this information, the user may construct his own component files. Component files constructed by the user must be in ASCII format. All parameters must be present in the order and location specified. If a parameter value (such as C_2 is not used, a "0" must be entered at the appropriate place as a "place holder" in order for the information to be properly read by SIMPLEV.

Vehicle Definition

The simulated vehicle is completely described mathematically by the coefficients in the road load equation. These coefficients are initially read from the vehicle files (i.e., those ASCII files with the ".VEH" extension). The user of SIMPLEV can write his own vehicle files and input them into the program at the appropriate prompt as described previously in this report.

Vehicle File

The vehicle file structure is shown by example of the IDSEP vehicle in Figure 32. Except for the first line of the vehicle file, numerical values should be the first to appear on a line. Descriptions of these values or notations for the convenience of the user may be entered after the numerical values on the same line. These notations are optional.

Line 1. The first line of the vehicle file must contain a character string. The information on this line is used to identify the vehicle in the program output.

Line 2. Line 2 contains the weight (in pounds) of the vehicle chassis and body. SIMPLEV will add the payload and calculated total battery weight to this weight to calculate the total vehicle weight. The battery weight is either with or without ancillary subsystems depending upon whether or not these are included in the battery file.

Line 3. The weight of any payload including driver (in pounds) should be entered on line 3.

Line 4. The vehicle aerodynamic drag coefficient, C_d, is dimensionless and should be entered on line 4.

Figure 32.

Line 5. The projected frontal area, A, of the vehicle is entered on line 5.

Lines 6 through 9. The coefficients of tire rolling resistance, C_0, C_1, C_2, and C_3 should be entered on lines 6, 7, 8, and 9 respectively. The respective dimensions of C_1, C_2, and C_3 are s/ft, $(s/ft)^2$ and, $(s/ft)^3$. C_0 is dimensionless.

Line 10. The coefficient of tire friction with the road surface, μ_o , is entered on line 10.

Line 11. The fraction of the fully loaded vehicle weight (including battery, passengers, payload, and APU components over the drive wheels) is entered on line 11. The values on lines 10 and 11 are used to determine the point of impending wheel skidding during acceleration.

Line 12. The tire rolling radius (in ft.) of the drive wheel(s) is entered on line 12.

Line 13. The gross vehicle weight rating in pounds (GVWR) is entered on line 13. If the total calculated vehicle weight exceeds this value, a caution warning is displayed on the "Change Vehicle Parameters Menu" during the input session and on the printed output. SIMPLEV will still run even if the GVWR is exceeded.

Line 14. The fraction of energy at the drive wheel(s) (a value between 0 and 1) which is available for regeneration is entered on line 14. A value of zero represents a vehicle with no regenerative braking, while a value of 1 represents a vehicle which brakes by regeneration only with no energy being absorbed by friction braking.

Line 15. Wheel bearing drag (τ_B) in lb-ft should be entered on line 15.

Most of the numerical values contained in this file will be displayed in the "Change Vehicle Parameters Menu" where the user will be given the opportunity to change or modify them.

Transmissions

Two types of transmissions or motor to wheel interfaces are possible in SIMPLEV. A conventional one or two speed geared transmission is described by the torque and speed versus efficiency file. This file defines the performance of the transmission in two quadrants of operation: positive speed and both positive and negative torque. A simple continuously variable transmission model is also available and is defined by parameters input from the PC keyboard.

One or Two Speed Geared Transmissions. This type of transmission is defined by the ASCII transmission files (those with ".TX" filename extensions) according to the example of the IDSEP transmission file shown in Figure 33. The efficiency matrix for the transmission is in terms of the transmission output torques and output speeds. In this example the values in the efficiency matrix are either unity or zero since the entire driveline efficiency is included on the motor efficiency matrix. Zero values reflect no regeneration below the equivalent driveshaft speed of 16 km/h (10 mph), or 148 rpm transmission output shaft speed. Although including zero efficiency is not a completely accurate description of vehicle operation, it produces the same result as would be accomplished in real hardware. The added benefit of this approach can be seen in the printed output where the average transmission loss during regeneration shows the average power which is dissipated in the vehicle brakes for the cycle if regeneration were deactivated below this speed.

The first line of the transmission file contains a character string identifier which will be used in the program output to identify the transmission used. Line 2 contains the value for the low ratio. Integer values on lines 3 and 4 define the size of the low gear efficiency matrix (rows and columns, respectively). The maximum size of the low gear efficiency matrix is limited to 20 rows by 30 columns.

The transmission matrix is entered next as shown in Figure 33. Column headings of transmission output torque (in lb-ft) are entered on line 5 in increasing order (negative torque represents the regenerative braking quadrant of operation). The transmission output speeds (in rpm) and efficiencies are then entered beginning on line 6. The first value to appear on these lines must be the speed coinciding with the efficiencies entered on the remainder of this line. The number of

Figure 33.

efficiencies entered must coincide with the number of torque entries on line 5. For single speed transmissions, the high gear data described below may be omitted.

Following the low gear transmission efficiency matrix, the second gear ratio and the vehicle speed (in mph) at which a gear change occurs is entered. If the vehicle speed is below this value, the transmission is assumed to operate in low gear. Likewise, if the vehicle speed is equal to or above this value, the transmission is assumed to operate in second gear. The speed at which the transmission is shifted may be changed on the "Change Vehicle Parameters Menu" during the input session. Next, the size of the high gear efficiency matrix (rows X columns) is defined by integer values. The high gear efficiency matrix is then entered as described above for the low gear efficiency matrix. The maximum size of the low gear efficiency matrix is limited to 20 rows by 30 columns. Comments following the numerical values for gear ratios and gear change speeds are for user convenience and are ignored by SIMPLEV.

During program execution, SIMPLEV performs a double linear interpolation from the data in the transmission efficiency matrix. If either the transmission output speed or output torque is beyond the data supplied, then a linear extrapolation is performed. This calculated efficiency is then used to determine the transmission input power.

Scaling of One or Two Speed Transmissions. During the input session, the user is given the opportunity of scaling the transmission. The user is prompted for scaling factors for output speed and output torque. If this option is chosen, the row and column values for speed and torque are multiplied by the scaling factor supplied. The efficiency values in the transmission matrix will therefore represent efficiencies at different torques and speeds than what is in the transmission file.

Continuously Variable Transmissions (CVT). The continuously variable transmission (CVT) is also rather simple. SIMPLEV assumes a constant efficiency (input by the user at the prompt). The user also inputs values for the low and high ratios of the CVT and the motor speed that is to be held constant. SIMPLEV will hold this motor speed by calculating the gear ratio for the CVT that is between the high and low ratios. The low ratio is used if the vehicle speed requires a ratio lower than the minimum and the hi ratio is used if the vehicle speed is higher than the maximum. The graph in Figure 34 is a qualitative representation of the CVT operation strategy and compares it to a 2-speed transmission.

Motors

Motors are defined by the ASCII motor files (those with ".MOT" filename extensions) according to the example of the IDSEP motor file shown in Figure 35. The numerical information in this file contains the efficiency matrix for the motor in terms of the motor output torque and output speed and the peak torque versus speed of the motor. In this example the values in the efficiency matrix include the transmission and inverter losses and represent the entire driveline efficiency.

The first line of the motor file contains a character string identifier which will be used in the program output to identify the motor used. Integer values on lines 2 and 3 define the size of the motor efficiency matrix (rows and columns, respectively). The maximum size of the motor efficiency matrix is limited to 20 rows by 30 columns.

The motor efficiency matrix is entered next as shown in Figure 35. Column headings of motor output torque (in lb-ft) are entered on line 4 in increasing order (negative torque represents the regenerative braking quadrant of operation). The motor output speeds (in rpm) and efficiencies are then entered beginning on line 5. The first value to appear on these lines must be the speed coinciding with the efficiencies entered on the remainder of this line. The last entry on each line is the motor peak torques (lb-ft) corresponding to the speed entered on the beginning of each line. The number of efficiencies entered must coincide with the number of torque entries on line 4. Character strings are allowed only on the first line of this file.

During program execution, SIMPLEV performs a double linear interpolation from the data in the motor efficiency matrix. If either the motor output speed or output torque is beyond the data supplied, then a linear extrapolation is performed. This calculated efficiency is then used to determine the motor input power.

Figure 34.

Figure 35.

Scaling Motors. During the input session, the user is given the opportunity of scaling the motor. The user is prompted for scaling factors for output speed and output torque. If this option is chosen, the row and column values for speed and torque are multiplied by the scaling factor supplied. The efficiency values in the motor matrix will therefore represent efficiencies at different torques and speeds than what is in the motor file.

Inverters/Controllers

Inverters or controllers are defined by the ASCII files (those with ".INV" filename extensions) according to the example of the IDSEP inverter file shown in Figure 36. The numerical information in this file contains the efficiency matrix for the inverter in terms of the motor output torque and speed and the peak inverter/controller current versus motor speed. In this example the values in the efficiency matrix are all unity since the entire driveline efficiency is included on the motor efficiency matrix.

The first line of the inverter/controller file contains a character string identifier which will be used in the program output to identify the inverter/controller used. The minimum inverter/controller voltage is entered on line 2. SIMPLEV will "clamp" this voltage during the simulation and not allow the battery voltage under load to depress below this value. The maximum current limit (in amperes) is entered on line 3. SIMPLEV will adjust this value according to the I/Imax versus motor speed information in this file. SIMPLEV will "clamp" this current during the simulation and not allow the battery current to exceed the calculated value of maximum current at any particular motor speed. Under either of these conditions, vehicle performance will be limited and a "best effort" attempt at the specified driving cycle will be simulated. Integer values on lines 4 and 5 define the size of the efficiency matrix (rows and columns, respectively). The maximum size of the inverter/controller efficiency matrix is limited to 20 rows by 30 columns. Comments following the numerical values for minimum voltage and maximum current are for user convenience and are ignored by SIMPLEV.

The inverter/controller efficiency matrix is entered next as shown in Figure 36. Column headings of motor output torque (in lb-ft) are entered on line 6 in increasing order (negative torque represents the regenerative braking quadrant of operation). The motor output speeds (in rpm) and efficiencies are then entered beginning on line 7. The first value to appear on these lines must be the

Figure 36.

speed coinciding with the efficiencies entered on the remainder of this line. The last entry on each line is the ratio of peak current attainable to the absolute peak current, I/Imax, corresponding to the speed entered on the beginning of each line. The number of efficiencies entered must coincide with the number of torque entries on line 6.

During program execution, SIMPLEV performs a double linear interpolation from the data in the inverter/controller efficiency matrix. If either the output speed or output torque is beyond the data supplied, then a linear extrapolation is performed. This calculated efficiency is then used to determine the battery traction power.

Scaling Inverter/Controllers. During the input session, the user is given the opportunity of scaling the inverter/controller. The user is prompted for scaling factors for output speed and output torque. If this option is chosen, the row and column values for speed and torque are multiplied by the scaling factor supplied. The efficiency values in the inverter/controller matrix will therefore represent efficiencies at different torques and speeds than what is in the file.

Battery Files

The battery is modeled using the open circuit voltage (VOC) and internal resistance (dV/dI) versus depth of discharge (DOD) characteristics. This information is read into SIMPLEV from the ASCII battery files (with the ".BTY" file extensions). Figure 37 listing the NIF-170 battery is an example a typical battery file.

The first line of the battery file contains a character string which is used by SIMPLEV to identify the battery used in the printed output. The second line is an integer value of the number of series components making up a module. SIMPLEV assumes cells and modules are connected in series. Line 3 contains the module battery weight in kilograms. The module weight is multiplied by the number of modules specified during the input session to arrive at the total battery weight.

The rated ampere-hour capacity of the battery is entered on line 4. This value is used in conjunction with the hour rating on line 7 to estimate the initial DOD of the battery at the beginning of each simulation run.

Figure 37.

The Peukert curve coefficients of the battery are entered on lines 6 and 6. The Puekert relationship is discussed above in previous sections. Line 7 contains the "C" hour rating as discussed above.

The remaining lines contain battery data giving the depth of discharge versus open circuit voltage and internal resistance (dI/dV), respectively. This information must be entered in ascending order of DOD and must cover the range of anticipated operation in the simulation. Data may be entered for any values of DOD. This matrix is limited to 11 rows of data. Notations for the convenience of the user may be entered after the values appearing on lines 2 through 7. This information is ignored by SIMPLEV.

Auxiliary Power Unit Files

The mathematical description of the APU consists of three separate files having the filename extensions of ".GEN", ".ENG", and ".CAT" for the generator, engine, and catalytic converter, respectively. These files are constructed as follows.

Generator File. Referring to Figure 38, the first line of this file contains a string identifier. Generally, this field is used to identify or name the generator modeled. The second line contains the generator weight (in pounds). This weight will be included in vehicle weight for the simulation. The third and fourth lines must contain the maximum and minimum generator output in watts. The maximum generator output will be used to determine the generator efficiency according to the calculated P/P_{max} from the efficiency table. During program execution, the generator output will not be allowed to operate below the minimum value entered while the APU is in the "on" state.

The remainder of the information supplied provides the simulation with two columns of data. On each line, provide the value for the generator P/P_{max} and generator efficiency, respectively. Up to 11 rows may be entered.

Engine File. Referring to Figure 39, the first line contains a character string denoting the type of fuel used by the engine. The second line provides two characteristics of this fuel, namely the fuel density (g/L) and the energy content (W·h/L), respectively. The third line of this file contains another

Figure 38.

Figure 39.

character string denoting the name of the engine for identification in the simulation output. Following on the next line is the weight (in pounds) of the engine. This weight will be included in vehicle weight for the simulation. The fifth line contains a value for the maximum engine output in watts. As in the case of the generator above, the maximum engine output will used to determine the emissions. Additionally, the engine cannot be operated above this value.

The next line contain the emissions (in grams) of HC and CO respectively, when the engine is first turned "on". Line 7 contains the HC and CO emissions (in grams) when the engine is turned "off".

The remainder of the information supplied provides the simulation with five of data. On each line, provide the value for the engine P/Pmax, brake specific fuel consumption (g/kW·h), HC emissions (g/kW·h), CO emissions (g/kW·h), and NOx (g/kW·h), respectively. Up to 11 rows of data may be entered.

Catalytic Converter. Referring to Figure 40, the catalytic converter file contains two lines of information. The first line contains a character string denoting the name identifier of the catalytic converter. The second line contains the characteristic time of warm-up of the catalyst, T_CHW, the cooling factor relative to heating, a, and the maximum catalytic converter efficiencies for HC, CO, and NO_X, respectively.

Driving Schedule Files

The ASCII driving schedule files contain the speed versus time information that is used by SIMPLEV. All driving schedule files have the ".CYC" file extension. The example in Figure 41 of the SAE J227a A cycle file supplied with SIMPLEV shows the format of these ASCII files. Line 1 contains a character string which identifies the driving cycle. This character string is used by SIMPLEV to identify the driving cycle in the output. The value on line 2 is the time increment (in seconds) for which the speeds listed in the file. The remainder of the file lists sequentially the speed versus time profile. SIMPLEV ignores the listed time, and speeds are in mph.

Figure 40

Figure 41

REFERENCES

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